Spatial organization of the bacterial cell

Solari, J.

2019

References

[1] Ron Milo. What is the total number of protein molecules per cell volume? A call to rethink some published values. *BioEssays*, 35(12):1050–1055, 2013.

[2] Howard Gest. The discovery of microorganisms by Robert Hooke and Antoni van Leeuwenhoek, Fellows of The Royal Society. *Notes Rec. R. Soc.*, 58(2):187–201, 2004.

[3] Malathy Krishnamurthy, Richard T Moore, Sathish Rajamani, and Rekha G Panchal. Bacterial genome engineering and synthetic biology: combating pathogens. *BMC Microbiol.*, 16(1):258, 2016.

[4] Ben N G Giepmans, Stephen R Adams, Mark H Ellisman, and Roger Y Tsien. The fluorescent toolbox for assessing protein location and function. *Science*, 312(5771):217–24, apr 2006.

[5] Derek Greenfield, Ann L McEvoy, Hari Shroff, Gavin E Crooks, Ned S Wingreen, Eric Betzig, and Jan Liphardt. Self-organization of the Escherichia coli chemotaxis network imaged with super-resolution light microscopy. *PLoS Biol.*, 7(6):e1000137, jun 2009.

[6] Edgar Huitema, Sean Pritchard, David Matteson, Sunish Kumar Radhakrishnan, and Patrick H. Viollier. Bacterial birth scar proteins mark future flagellum assembly site. *Cell*, 124(5):1025–1037, 2006.

[7] Hubert Lam, Whitman B. Schofield, and Christine Jacobs-Wagner. A landmark protein essential for establishing and perpetuating the polarity of a bacterial cell. *Cell*, 124(5):1011–1023, 2006.

[8] Anuradha Janakiraman and Marcia B Goldberg. From the Cover: Evidence for polar positional information independent of cell division and nucleoid occlusion. *Pnas*, 101(3):835–840, 2004.

[9] David H. Edwards and Jeffery Errington. The Bacillus subtilis DivIVA protein targets to the division septum and controls the site specificity of cell division. *Mol. Microbiol.*, 24(5):905–915, 1997.

[10] David Z. Rudner and Richard Losick. Protein subcellular localization in bacteria. *Cold Spring Harb. Perspect. Biol.*, 2(4):1–14, 2010.

[11] Achillefs N. Kapanidis, Stephan Uphoff, and Mathew Stracy. Understanding Protein Mobility in Bacteria by Tracking Single Molecules. *J. Mol. Biol.*, 2018.

[12] Susan M. Sullivan and Janine R. Maddock. Bacterial division: Finding the dividing line. *Curr. Biol.*, 10(6):249–252, 2000.

[13] Sonja Schulmeister, Michaela Ruttorf, Sebastian Thiem, David Kentner, Dirk Lebiedz, and Victor Sourjik. Protein exchange dynamics at chemoreceptor clusters in Escherichia coli. *Proc. Natl. Acad. Sci. U. S. A.*, 105(17):6403–6408, 2008.

[14] Sattar Taheri-Araghi, Serena Bradde, John T. Sauls, Norbert S. Hill, Petra Anne Levin, Johan Paulsson, Massimo Vergassola, and Suckjoon Jun. Cell-size control and homeostasis in bacteria. *Curr. Biol.*, 25(3):385–391, 2015.

[15] Jacques Monod. a Certain Number. *Annu. Rev. M*, 3(Xl):371–394, 1949.

[16] Margolin W. Ftsz and the division of prokaryotics cells and organelles. *Nature reviews Molecular cell biology.*, 6:862–871, 2005.

[17] C A Hale, H Meinhardt, and P A de Boer. Dynamic localization cycle of the cell division regulator MinE in Escherichia coli. *EMBO J.*, 20(7):1563–72, 2001.

[18] Barbara Di Ventura and Victor Sourjik. Self-organized partitioning of dynamically localized proteins in bacterial cell division. *Mol. Syst. Biol.*, 7(457):457, jan 2011.

[19] Victor Sourjik and Judith P Armitage. Spatial organization in bacterial chemotaxis. *EMBO J.*, 29(16):2724–2733, 2010.

[20] P. Hammar, P. Leroy, a. Mahmutovic, E. G. Marklund, O. G. Berg, and J. Elf. The lac Repressor Displays Facilitated Diffusion in Living Cells. *Science (80-.).*, 336(6088):1595–1598, 2012.

[21] Remus T Dame, Olga J Kalmykowa, and David C Grainger. Chromosomal macrodomains and associated proteins: implications for DNA organization and replication in gram negative bacteria. *PLoS Genet.*, 7(6):e1002123, jun 2011.

[22] Joanna Hołówka, Damian Trojanowski, Katarzyna Ginda, Bartosz Wojtaś, Bartłomiej Gielniewski, Dagmara Jakimowicz, and Jolanta Zakrzewska-Czerwińska. HupB Is a Bacterial Nucleoid-Associated Protein with an Indispensable Eukaryotic-Like Tail. *MBio*, 8(6):e01272–17, 2017.

[23] R. Carballido-Lopez. The Bacterial Actin-Like Cytoskeleton. *Microbiol. Mol. Biol. Rev.*, 70(4):888–909, 2006.

[24] Henrik Strahl, Frank Bürmann, and Leendert W Hamoen. The actin homologue MreB organizes the bacterial cell membrane. *Nat. Commun.*, 5:3442, 2014.

[25] George H. Wadhams and Judith P. Armitage. Making Sense of it All: Bacterial Chemotaxis. *Nat. Rev. Mol. Cell Biol.*, 5(December):1024–1037, 2004.

[26] Howard C. Berg and Richard M. Berry. *E. Coli in motion*, volume 58. 2005.

[27] J Adler. A method for measuring chemotaxis and use of the method to determine optimum conditions for chemotaxis by Escherichia coli. *J. Gen. Microbiol.*, 74(1):77–91, 1973.

[28] a. Briegel, X. Li, a. M. Bilwes, K. T. Hughes, G. J. Jensen, and B. R. Crane. Bacterial chemoreceptor arrays are hexagonally packed trimers of receptor dimers networked by rings of kinase and coupling proteins. *Proc. Natl. Acad. Sci.*, 109(10):3766–3771, 2012.

[29] David Kentner, Sebastian Thiem, Markus Hildenbeutel, and Victor Sourjik. Determinants of chemoreceptor cluster formation in Escherichia coli. *Mol. Microbiol.*, 61(2):407–417, 2006.

[30] Victor Sourjik and Howard C Berg. Functional interactions between receptors in bacterial chemotaxis. *Nature*, 428(March):1–4, 2004.

[31] Allison C. Lamanna, George W. Ordal, and Laura L. Kiessling. Large increases in attractant concentration disrupt the polar localization of bacterial chemoreceptors. *Mol. Microbiol.*, 57(3):774–785, 2005.

[32] Motohiro Homma, Daisuke Shiomi, Michio Homma, and Ikuro Kawagishi. Attractant binding alters arrangement of chemoreceptor dimers within its cluster at a cell pole. *Proc. Natl. Acad. Sci. U. S. A.*, 101(10):3462–7, 2004.

[33] M. Jack Borrok, Erin M. Koionko, and Laura L. Kiessling. Chemical probes of bacterial signal transduction reveal that repellents stabilize and attractants destabilize the chemoreceptor array. *ACS Chem. Biol.*, 3(2):101–109, 2008.

[34] Ariane Briegel, Morgan Beeby, Martin Thanbichler, and Grant J. Jensen. Activated chemoreceptor arrays remain intact and hexagonally packed. *Mol. Microbiol.*, 82(3):748–757, 2011.

[35] Kang Wu, Hanna E. Walukiewicz, George D. Glekas, George W. Ordal, and Christopher V. Rao. Attractant binding induces distinct structural changes to the polar and lateral signaling clusters in Bacillus subtilis chemotaxis. *J. Biol. Chem.*, 286(4):2587–2595, 2011.

[36] Louisa Liberman, Howard C. Berg, and Victor Sourjik. Effect of chemoreceptor modification on assembly and activity of the receptor-kinase complex in Escherichia coli. *J. Bacteriol.*, 186(19):6643–6646, 2004.

[37] Sho Asakura and Fumio Oosawa. Interaction between particles suspended in solutions of macromolecules. *J. Polym. Sci.*, 33(126):183–192, 1958.

[38] Kim A. Sharp. Analysis of the size dependence of macromolecular crowding shows that smaller is better. *Proc. Natl. Acad. Sci.*, 112(26):7990–7995, 2015.

[39] R. John Ellis. Macromolecular crowding: Obvious but underappreciated. *Trends Biochem. Sci.*, 26(10):597–604, 2001.

[40] Anja Nenninger, Giulia Mastroianni, and Conrad W. Mullineaux. Size dependence of protein diffusion in the cytoplasm of Escherichia coli. *J. Bacteriol.*, 192(18):4535–4540, 2010.

[41] Geert Van Den Bogaart, Nicolaas Hermans, Victor Krasnikov, and Bert Poolman. Protein mobility and diffusive barriers in Escherichia coli: Consequences of osmotic stress. *Mol. Microbiol.*, 64(3):858–871, 2007.

[42] Steven B Zimmerman and Allen P Minton. MACROMOLECULAR CROWDING: Biochemical, Biophysical and Physiological Consequences. *Annu. Rev. Biophys.*, 22:27–65, 1993.

[43] J. Pelletier, K. Halvorsen, B.-Y. Ha, R. Paparcone, S. J. Sandler, C. L. Woldringh, W. P. Wong, and S. Jun. Physical manipulation of the Escherichia coli chromosome reveals its soft nature. *Proc. Natl. Acad. Sci.*, 109(40):E2649–E2656, 2012.

[44] Sónia Cunha, Conrad L Woldringh, and Theo Odijk. Polymer-Mediated Compaction and Internal Dynamics of Isolated Escherichia coli Nucleoids. *J. Struct. Biol.*, 136(1):53–66, 2001.

[45] Suckjoon Jun. Chromosome, cell cycle, and entropy. *Biophys. J.*, 108(4):785–786, 2015.

[46] Gernot Guigas and Matthias Weiss. Effects of protein crowding on membrane systems. *Biochim. Biophys. Acta - Biomembr.*, 1858(10):2441–2450, 2016.

[47] Joseph E. Goose and Mark S P Sansom. Reduced Lateral Mobility of Lipids and Proteins in Crowded Membranes. *PLoS Comput. Biol.*, 9(4), 2013.

[48] Martin Lindén, Pierre Sens, and Rob Phillips. Entropic tension in crowded membranes. *PLoS Comput. Biol.*, 8(3):1–10, 2012.

[49] Felix Höfling and Thomas Franosch. Anomalous transport in the crowded world of biological cells. *Reports Prog. Phys.*, 76(4), 2013.

[50] Grzegorz Wieczorek and Piotr Zielenkiewicz. Influence of Macromolecular Crowding on Protein-Protein Association Rates—a Brownian Dynamics Study. *Biophys. J.*, 95(11):5030–5036, dec 2008.

[51] Jay R. Wenner and Victor A. Bloomfield. Crowding effects on EcoRV kinetics and binding. *Biophys. J.*, 77(6):3234–3241, 1999.

[52] Jonas van den Berg, Arnold J. Boersma, and Bert Poolman. Microorganisms maintain crowding homeostasis. *Nat. Rev. Microbiol.*, 15(5):309–318, 2017.

[53] Germán Rivas and Allen P. Minton. Macromolecular Crowding In Vitro, In Vivo, and In Between. *Trends Biochem. Sci.*, 41(11):970–981, 2016.

[54] Arnold J Boersma, Inge S Zuhorn, and Bert Poolman. A sensor for quantification of macromolecular crowding in living cells. *Nat. Methods*, 12(3):227–9, 1 p following 229, 2015.

[55] IVAR LOSSIUS KJELL KLEPPE, STEINAR VREB. The Bacterial Nucleoid. 1624(2):1–13, 2017.

[56] Remus T. Dame. The role of nucleoid-associated proteins in the organization and compaction of bacterial chromatin. *Mol. Microbiol.*, 56(4):858–870, 2005.

[57] Remus T Dame, Maarten C Noom, and Gijs J L Wuite. Bacterial chromatin organization by H-NS protein unravelled using dual DNA manipulation. *Nature*, 444(7117):387–390, 2006.

[58] Shane C Dillon and Charles J Dorman. Bacterial nucleoid-associated proteins, nucleoid structure and gene expression. *Nat. Rev. Microbiol.*, 8(3):185–95, 2010.

[59] Steven F Lee, Michael A Thompson, Monica A Schwartz, Lucy Shapiro, and W E Moerner. Super-resolution imaging of the nucleoid-associated protein HU in Caulobacter crescentus. *Biophys. J.*, 100(7):L31–3, apr 2011.

[60] Anna S. Wegner, Svetlana Alexeeva, Theo Odijk, and Conrad L. Woldringh. Characterization of Escherichia coli nucleoids released by osmotic shock. *J. Struct. Biol.*, 178(3):260–269, 2012.

[61] Paul a Wiggins, Keith C Cheveralls, Joshua S Martin, Robert Lintner, and Jané Kondev. Strong intranucleoid interactions organize the Escherichia coli chromosome into a nucleoid filament. *Proc. Natl. Acad. Sci. U. S. A.*, 107(11):4991–4995, 2010.

[62] Anjana Badrinarayanan, Christian Lesterlin, Rodrigo Reyes-Lamothe, and David Sherratt. The escherichia coli SMC complex, MukBEF, shapes nucleoid organization independently of DNA replication. *J. Bacteriol.*, 194(17):4669–4676, 2012.

[63] Anjana Badrinarayanan, Rodrigo Reyes-Lamothe, Stephan Uphoff, Mark C Leake, and David J Sherratt. In vivo architecture and action of bacterial structural maintenance of chromosome proteins. *Sci. New York NY*, 338(6106):528–531, 2012.

[64] Tung B K Le, Maxim V Imakaev, Leonid a Mirny, Michael T Laub, and High-resolution Mapping. High-Resolution Mapping of the Spatial Organization of a Bacterial Chromosome. *Science*, 731(October), oct 2013.

[65] Sun-Hae Hong, Esteban Toro, Kim I Mortensen, Mario a Díaz de la Rosa, Sebastian Doniach, Lucy Shapiro, Andrew J Spakowitz, and Harley H McAdams. Caulobacter chromosome in vivo configuration matches model predictions for a supercoiled polymer in a cell-like confinement. *Proc. Natl. Acad. Sci. U. S. A.*, 110(5):1674–9, jan 2013.

[66] Juin Kim, Chanil Jeon, Hawoong Jeong, Youngkyun Jung, and Bae-Yeun Ha. A polymer in a crowded and confined space: effects of crowder size and poly-dispersity. *Soft Matter*, 11(10):1877–1888, 2015.

[67] F.C. Neidhardt and R. Curtiss. *Escherichia Coli and Salmonella: Cellular and Molecular Biology*. Number v. 1 in Escherichia Coli and Salmonella: Cellular and Molecular Biology. ASM Press, 1996.

[68] Pierre-Gilles De Gennes and Pierre-Gilles Gennes. *Scaling concepts in polymer physics*. Cornell university press, 1979.

[69] Cedric Cagliero, Ralph S Grand, M Beatrix Jones, Ding J Jin, and Justin M O'Sullivan. Genome conformation capture reveals that the Escherichia coli chromosome is organized by replication and transcription. *Nucleic Acids Res.*, (16):1–14, apr 2013.

[70] Bradley R Parry, Ivan V Surovtsev, Matthew T Cabeen, Corey S O‚Äôhern, Eric R Dufresne, and Christine Jacobs-Wagner. The Bacterial Cytoplasm Has Glass-like Properties and Is Fluidized by Metabolic Activity. *Cell*, pages 1–12, 2013.

[71] C Robinow and E Kellenberger. The bacterial nucleoid revisited. *Microbiol. Rev.*, 58(2):211–32, 1994.

[72] Sviatlana Shashkova and Mark C Leake. Single-molecule fluorescence microscopy review: shedding new light on old problems. *Biosci. Rep.*, 0(July):BSR20170031, 2017.

[73] Christian Combs. Fluorescence Microscopy: A Concise Guide to Current Imaging Methods. *Curr. Protoc. Neurosci.*, pages 1–19, 2010.

[74] Eric Betzig, George H Patterson, Rachid Sougrat, O Wolf Lindwasser, Scott Olenych, Juan S Bonifacino, Michael W Davidson, Jennifer Lippincott-Schwartz, and Harald F Hess. Imaging intracellular fluorescent proteins at nanometer resolution. *Science (80-.).*, 313(5793):1642–1645, 2006.

[75] Mats G L Gustafsson. Nonlinear structured-illumination microscopy: Wide-field fluorescence imaging with theoretically unlimited resolution. *Proc. Natl. Acad. Sci. U. S. A.*, 102(37):13081–13086, 2005.

[76] Xiaowei Zhuang. Nano-imaging with Storm. *Nat. Photonics*, 3(7):365–367, 2009.

[77] Ulrike Endesfelder, Sebastian Malkusch, Benjamin Flottmann, Justine Mondry, Piotr Liguzinski, Peter J Verveer, and Mike Heilemann. Chemically induced photoswitching of fluorescent probes–a general concept for super-resolution microscopy. *Molecules*, 16(4):3106–18, jan 2011.

[78] Russell E Thompson, Daniel R Larson, and Watt W Webb. Precise nanometer localization analysis for individual fluorescent probes. *Biophys. J.*, 82(5):2775–2783, may 2002.

[79] M. Ovesny, P. K i ek, J. Borkovec, Z. vindrych, and G. M. Hagen. ThunderSTORM: a comprehensive ImageJ plug-in for PALM and STORM data analysis and super-resolution imaging. *Bioinformatics*, 30(16):2389–2390, 2014.

[80] Hari Shroff, Catherine G Galbraith, James a Galbraith, and Eric Betzig. Live-cell photoactivated localization microscopy of nanoscale adhesion dynamics. *Nat. Methods*, 5(5):417–23, may 2008.

[81] Suliana Manley, Jennifer M Gillette, George H Patterson, Hari Shroff, Harald F Hess, Eric Betzig, and Jennifer Lippincott-Schwartz. High-density mapping of single-molecule trajectories with photoactivated localization microscopy. *Nat. Methods*, 5(2):155–157, feb 2008.

[82] Zhen Liu, Dong Xing, Qian Peter Su, Yun Zhu, Jiamei Zhang, Xinyu Kong, Boxin Xue, Sheng Wang, Hao Sun, Yile Tao, and Yujie Sun. Super-resolution imaging and tracking of protein-protein interactions in sub-diffraction cellular space. *Nat. Commun.*, 5:4443, 2014.

[83] Mathew Stracy, Christian Lesterlin, Federico Garza de Leon, Stephan Uphoff, Pawel Zawadzki, and Achillefs N Kapanidis. Live-cell superresolution microscopy reveals the organization of RNA polymerase in the bacterial nucleoid. *Proc. Natl. Acad. Sci. U. S. A.*, 112(32):E4390–9, 2015.

[84] Nastaran Hadizadeh Yazdi, Calin C. Guet, Reid C. Johnson, and John F. Marko. Variation of the folding and dynamics of the Escherichia coli chromosome with growth conditions. *Mol. Microbiol.*, 86(6):1318–1333, 2012.

[85] Preeti Srivastava, Gäelle Demarre, Tatiana S. Karpova, James McNally, and Dhruba K. Chattoraj. Changes in nucleoid morphology and origin localization upon inhibition or alteration of the actin homolog, MreB, of Vibrio cholerae. *J. Bacteriol.*, 189(20):7450–7463, 2007.

[86] Stephen A Sciochetti, Garry W Blakely, and J Patrick. Growth Phase Variation in Cell and Nucleoid Morphology in a Bacillus subtilis recA Mutant Growth Phase Variation in Cell and Nucleoid Morphology in a Bacillus subtilis recA Mutant. 183(9):2963–2968, 2001.

[87] Daphna Frenkiel-Krispin, Irit Ben-Avraham, Joseph Englander, Eyal Shimoni, Sharon G. Wolf, and Abraham Minsky. Nucleoid restructuring in stationary-state bacteria. *Mol. Microbiol.*, 51(2):395–405, 2004.

[88] Ali Azam Talukder and Akira Ishihama. Growth phase dependent changes in the structure and protein composition of nucleoid in Escherichia coli. *Sci. China Life Sci.*, 58(9):902–911, 2015.

[89] Philippe Nghe, Sarah Boulineau, Sebastian Gude, Pierre Recouvreux, Jeroen S. van Zon, and Sander J. Tans. Microfabricated Polyacrylamide Devices for the Controlled Culture of Growing Cells and Developing Organisms. *PLoS One*, 8(9):1–11, 2013.

[90] Avelino Javer, Nathan J. Kuwada, Zhicheng Long, Vincenzo G. Benza, Kevin D. Dorfman, Paul a. Wiggins, Pietro Cicuta, and Marco Cosentino Lagomarsino. Persistent super-diffusive motion of Escherichia coli chromosomal loci. *Nat. Commun.*, 5(May):1–8, 2014.

[91] H.C. Berg. A miniature flow cell designed for rapid exchange of media under high-power microscope objectives. *Microbiology*, 130(11):2915–2920, 1984.

[92] T Katsu, T Tsuchiya, and Y Fujita. Dissipation of membrane potential of Escherichia coli cells induced by macromolecular polylysine. *Biochem. Biophys. Res. Commun.*, 122(1):401–406, 1984.

[93] Ping Wang, Lydia Robert, James Pelletier, Wei Lien Dang, Francois Taddei, Andrew Wright, and Suckjoon Jun. Robust growth of Escherichia coli. *Curr. Biol.*, 20(12):1099–1103, 2011.

[94] Douglas B Weibel, Willow R Diluzio, and George M Whitesides. Microfabrication meets microbiology. *Nat. Rev. Microbiol.*, 5(3):209–18, 2007.

[95] Yu Tanouchi, Anand Pai, Heungwon Park, Shuqiang Huang, Rumen Stamatov, Nicolas E Buchler, and Lingchong You. A noisy linear map underlies oscillations in cell size and gene expression in bacteria. *Nature*, 523(7560):357–360, jun 2015.

[96] Yu Tanouchi, Anand Pai, Heungwon Park, Shuqiang Huang, Nicolas E. Buchler, and Lingchong You. Long-term growth data of Escherichia coli at a single-cell level. *Sci. Data*, 4:1–5, 2017.

[97] Brenda Youngren, Henrik Jörk Nielsen, Suckjoon Jun, and Stuart Austin. The multi-fork Escherichia coli chromosome is a self-duplicating and self-segregating thermodynamic ring polymer. *Genes Dev.*, 28(1):71–84, 2014.

[98] Ping Wang, Lydia Robert, James Pelletier, Wei Lien Dang, Francois Taddei, Andrew Wright, and Suckjoon Jun. Robust growth of escherichia coli. *Current biology*, 20(12):1099–1103, 2010.

[99] Esther Wertz, Benjamin P. Isaacoff, Jessica D. Flynn, and Julie S. Biteen. Single-Molecule Super-Resolution Microscopy Reveals How Light Couples to a Plasmonic Nanoantenna on the Nanometer Scale. *Nano Lett.*, 15(4):2662–2670, 2015.

[100] Hongzhen Lin, Silvia P. Centeno, Liang Su, Bart Kenens, Susana Rocha, Michel Sliwa, Johan Hofkens, and Hiroshi Uji-I. Mapping of surface-enhanced fluorescence on metal nanoparticles using super-resolution photoactivation localization microscopy. *ChemPhysChem*, 13(4):973–981, 2012.

[101] Xiaochun Zhou, Nesha May Andoy, Guokun Liu, Eric Choudhary, Kyu Sung Han, Hao Shen, and Peng Chen. Quantitative super-resolution imaging uncovers reactivity patterns on single nanocatalysts. *Nat. Nanotechnol.*, 7(4):237–241, 2012.

[102] Eric Johlin, Jacopo Solari, Sander A. Mann, Jia Wang, Thomas S. Shimizu, and Erik C. Garnett. Super-resolution imaging of light-matter interactions near single semiconductor nanowires. *Nat. Commun.*, 7:1–6, 2016.

[103] Eric Betzig. Single Molecules, Cells, and Super-Resolution Optics (Nobel Lecture). *Angew. Chemie - Int. Ed.*, 54(28):8034–8053, 2015.

[104] SW Hell. Far-field optical nanoscopy. *Science (80-.).*, 316(2007):246–9, 2007.

[105] Bo Huang, Mark Bates, and Xiaowei Zhuang. Super-Resolution Fluorescence Microscopy. *Ann. Rev. Biochem.*, 78(1):993–1016, 2009.

[106] Eric Betzig. Proposed method for molecular optical imaging. *Opt. Lett.*, 20(3):237–9, 1995.

[107] Brian P English, Vasili Hauryliuk, Arash Sanamrad, Stoyan Tankov, Nynke H Dekker, and Johan Elf. Single-molecule investigations of the stringent response machinery in living bacterial cells. *Proc. Natl. Acad. Sci. U. S. A.*, 108(31):E365–E373, 2011.

[108] L Niu and J Yu. Investigating intracellular dynamics of FtsZ cytoskeleton with photoactivation single-molecule tracking. *Biophys. J.*, 95(4):2009–2016, 2008.

[109] Victor Sourjik, Ady Vaknin, Thomas S. Shimizu, and Howard C. Berg. In Vivo Measurement by FRET of Pathway Activity in Bacterial Chemotaxis. In *Methods Enzymol.*, volume 423, pages 365–391. 2007.

[110] Egon Amann, Birgit Ochs, and K.J. Abel. Tightly regulated tac promoter vectors useful for the expression of unfused and fused proteins in escherichia coli. 69:301–15, 10 1988.

[111] L. M. Guzman, D. Belin, M. J. Carson, and J. Beckwith. Tight regulation, modulation, and high-level expression by vectors containing the arabinose P(BAD) promoter. *J. Bacteriol.*, 177(14):4121–4130, 1995.

[112] Leonard Guarente. Yeast promoters and lacz fusions designed to study expression of cloned genes in yeast. 101:181–91, 02 1983.

[113] Peter Ames, Claudia a Studdert, Rebecca H Reiser, and John S Parkinson. Collaborative signaling by mixed chemoreceptor teams in Escherichia coli. *Proc. Natl. Acad. Sci. U. S. A.*, 99(10):7060–7065, 2002.

[114] Robert G Endres, Olga Oleksiuk, Clinton H Hansen, Yigal Meir, Victor Sourjik, and Ned S Wingreen. Variable sizes of Escherichia coli chemoreceptor signaling teams. *Mol. Syst. Biol.*, 4(211):211, jan 2008.

[115] Vered Frank, Germán E Piñas, Harel Cohen, John S Parkinson, and Ady Vaknin. Networked Chemoreceptors Benefit Bacterial Chemotaxis Performance. *MBio*, 7(6):1–9, dec 2016.

[116] Rajalakshmi Srinivasan, Vittore Ferdinando Scolari, Marco Cosentino Lagomarsino, Aswin Sai Narain, and Aswin Sai Narain Seshasayee. The genome-scale interplay amongst xenogene silencing, stress response and chromosome architecture in Escherichia coli. *Nucleic Acids Res.*, 43(1):295–308, 2015.

[117] M. Daszykowski and B. Walczak. Density-Based Clustering Methods. In *Compr. Chemom.*, volume 70, pages 635–654. Elsevier, mar 2009.

[118] Keegan Colville, Nicolas Tompkins, Andrew D. Rutenberg, and Manfred H. Jericho. Effects of poly(L-lysine) substrates on attached escherichia coli bacteria. *Langmuir*, 26(4):2639–2644, 2010.

[119] Khuloud Jaqaman, Dinah Loerke, Marcel Mettlen, Hirotaka Kuwata, Sergio Grinstein, Sandra L Schmid, and Gaudenz Danuser. Robust single-particle tracking in live-cell time-lapse sequences. *Nat. Methods*, 5(8):695–702, aug 2008.

[120] Sebastian Thiem, David Kentner, and Victor Sourjik. Positioning of chemosensory clusters in E. coli and its relation to cell division. *EMBO J.*, 26(6):1615–23, mar 2007.

[121] Hironori Niki, Yoshiharu Yamaichi, and Sota Hiraga. Dynamic organization of chromosomal DNA in Escherichia coli Dynamic organization of chromosomal DNA in Escherichia coli. pages 212–223, 2000.

[122] Michèle Valens, Stéphanie Penaud, Michèle Rossignol, François Cornet, and Frédéric Boccard. Macrodomain organization of the Escherichia coli chromosome. *EMBO J.*, 23(21):4330–4341, 2004.

[123] Olivier Espeli, Romain Mercier, and Frédéric Boccard. DNA dynamics vary according to macrodomain topography in the E. coli chromosome. *Mol. Microbiol.*, 68(6):1418–27, jun 2008.

[124] Douglas F. Browning, Jeffrey A. Cole, and Stephen J W Busby. Regulation by nucleoid-associated proteins at the Escherichia coli nir operon promoter. *J. Bacteriol.*, 190(21):7258–7267, 2008.

[125] Sophie Nolivos and David Sherratt. The bacterial chromosome: Architecture and action of bacterial SMC and SMC-like complexes. *FEMS Microbiol. Rev.*, 38(3):380–392, 2014.

[126] Christoph Spahn, Ulrike Endesfelder, and Mike Heilemann. Super-resolution imaging of Escherichia coli nucleoids reveals highly structured and asymmetric segregation during fast growth. *J. Struct. Biol.*, pages 1–7, jan 2014.

[127] Esteban Toro and Lucy Shapiro. Bacterial chromosome organization and segregation. *Cold Spring Harb. Perspect. Biol.*, 2(2):a000349, feb 2010.

[128] Rodrigo Reyes-Lamothe, Emilien Nicolas, and David J. Sherratt. Chromosome Replication and Segregation in Bacteria. *Annu. Rev. Genet.*, 46(1):121–143, 2012.

[129] Jay K Fisher, Aude Bourniquel, Guillaume Witz, Beth Weiner, Mara Prentiss, and Nancy Kleckner. Four-Dimensional Imaging of E. coli Nucleoid Organization and Dynamics in Living Cells. *Cell*, 153(4):882–95, may 2013.

[130] Muriel Wery, Conrad L. Woldringh, and Josette Rouviere-Yaniv. HU-GFP and DAPI co-localize on the Escherichia coli nucleoid. *Biochimie*, 83(2):193–200, 2001.

[131] Somenath Bakshi, Heejun Choi, Nambirajan Rangarajan, Kenneth J. Barns, Benjamin P. Bratton, and James C. Weisshaar. Nonperturbative imaging of nucleoid morphology in live bacterial cells during an antimicrobial peptide attack. *Appl. Environ. Microbiol.*, 80(16):4977–4986, 2014.

[132] Optical Setup, S. Wang, J. R. Moffitt, G. T. Dempsey, X. S. Xie, and X. Zhuang. Characterization and development of photoactivatable fluorescent proteins for single-molecule-based superresolution imaging. *Proc. Natl. Acad. Sci.*, 111(23):1–9, may 2014.

[133] Diana Di Paolo, Oshri Afanzar, Judith P. Armitage, and Richard M. Berry. Single-molecule imaging of electroporated dye-labelled CheY in live <i>Escherichia coli</i>. *Philos. Trans. R. Soc. B Biol. Sci.*, 371(1707):20150492, 2016.

[134] T Atlung and H Ingmer. H-NS: a modulator of environmentally regulated gene expression. *Mol. Microbiol.*, 24(1):7–17, 1997.

[135] Bo Huang, Wenqin Wang, Mark Bates, and Xiaowei Zhuang. Three-dimensional super-resolution imaging by stochastic optical reconstruction microscopy. *Science*, 319(5864):810–3, feb 2008.

[136] Idit Anna Berlatzky, Alex Rouvinski, and Sigal Ben-Yehuda. Spatial organization of a replicating bacterial chromosome. *Proc. Natl. Acad. Sci. U. S. A.*, 105(37):14136–40, sep 2008.

[137] Wenquin Wang, Gene-Wei Li, Chongyi Chen, Sunny X. Xie, and Xiaowei Zhuang. Live Bacteria. *Science (80-.).*, 333(6048):1445–1449, 2012.

[138] Rotem Gura Sadovsky, Shlomi Brielle, Daniel Kaganovich, and Jeremy L. England. Measurement of Rapid Protein Diffusion in the Cytoplasm by Photo-Converted Intensity Profile Expansion. *Cell Rep.*, 18(11):2795–2806, 2017.

[139] Sun-Hae Hong and Harley H McAdams. Compaction and transport properties of newly replicated Caulobacter crescentus DNA. *Mol. Microbiol.*, 82(6):1–10, dec 2011.

[140] C Robinett, a Straight, G Li, C Willhelm, G Sudlow, a Murray, and a S Belmont. In vivo loclization of DNA sequences and visualization of large-scale chromatin organizacion using lac operator/represor recognition. *J. Cell Biol.*, 135(6- part 2):1685–1700, 1996.

[141] MC Joshi and Aude Bourniquel. Escherichia coli sister chromosome separation includes an abrupt global transition with concomitant release of late-splitting intersister snaps. *Proc. . . .* , 108(7):2765–2770, feb 2011.

[142] Xindan Wang, Xun Liu, Christophe Possoz, and David J Sherratt. The two Escherichia coli chromosome arms locate to separate cell halves. *Genes Dev.*, 20(13):1727–31, jul 2006.

[143] Paul a Wiggins, Keith C Cheveralls, Joshua S Martin, Robert Lintner, and Jané Kondev. Strong intranucleoid interactions organize the Escherichia coli chromosome into a nucleoid filament. *Proc. Natl. Acad. Sci. U. S. A.*, 107(11):4991–5, mar 2010.

[144] Patrick H Viollier, Martin Thanbichler, Patrick T McGrath, Lisandra West, Maliwan Meewan, Harley H McAdams, and Lucy Shapiro. Rapid and sequential movement of individual chromosomal loci to specific subcellular locations during bacterial DNA replication. *Proc. Natl. Acad. Sci. U. S. A.*, 101(25):9257–62, jun 2004.

[145] Zach Hensel, Xiaoli Weng, Arvin Cesar Lagda, and Jie Xiao. Transcription-factor-mediated DNA looping probed by high-resolution, single-molecule imaging in live E. coli cells. *PLoS Biol.*, 11(6):e1001591, jan 2013.

[146] R M Dickson, a B Cubitt, R Y Tsien, and W E Moerner. On/off blinking and switching behaviour of single molecules of green fluorescent protein. *Nature*, 388(6640):355–8, jul 1997.

[147] Mark C Leake, Nicholas P Greene, Rachel M Godun, Thierry Granjon, Grant Buchanan, Shuyun Chen, Richard M Berry, Tracy Palmer, and Ben C Berks. Variable stoichiometry of the TatA component of the twin-arginine protein transport system observed by in vivo single-molecule imaging. *Proc. Natl. Acad. Sci. U. S. A.*, 105(40):15376–81, oct 2008.

[148] Avelino Javer, Zhicheng Long, Eileen Nugent, Marco Grisi, Kamin Siriwatwetchakul, Kevin D. Dorfman, Pietro Cicuta, and Marco Cosentino Lagomarsino. Short-time movement of E. coli chromosomal loci depends on coordinate and subcellular localization. *Nat. Commun.*, 4(May):1–8, 2013.

[149] B. Alberts, D. Bray, J. Lewis, M. Raff, K. Roberts, and J.D. Watson. *Molecular Biology of the Cell*. Garland, 4th edition, 2002.

[150] Sin Yi Lee, Ci Ji Lim, Peter Dröge, and Jie Yan. Regulation of Bacterial DNA Packaging in Early Stationary Phase by Competitive DNA Binding of Dps and IHF. *Sci. Rep.*, 5(December):1–10, 2015.

[151] Bradley R. Parry, Ivan V. Surovtsev, Matthew T. Cabeen, Corey S. O'Hern, Eric R. Dufresne, and Christine Jacobs-Wagner. The bacterial cytoplasm has glass-like properties and is fluidized by metabolic activity. *Cell*, 156(1-2):183–194, 2014.

[152] Akshay K. Harapanahalli, Jessica A. Younes, Elaine Allan, Henny C. van der Mei, and Henk J. Busscher. Chemical Signals and Mechanosensing in Bacterial Responses to Their Environment. *PLoS Pathog.*, 11(8):1–6, 2015.

[153] Melissa B Miller and Bonnie L Bassler. Ensing in. *Annu. Rev. Microbiol.*, 55:165–99, 2001.

[154] Anna Maria Giuliodori, Claudio O. Gualerzi, Sara Soto, Jordi Vila, and María M. Tavío. Review on bacterial stress topics. *Ann. N. Y. Acad. Sci.*, 1113:95–104, 2007.

[155] Donna R Whelan and Toby D M Bell. Image artifacts in Single Molecule Localization Microscopy: why optimization of sample preparation protocols matters. *Sci. Rep.*, 5:7924, 2015.

[156] Zhe Liu, Luke D. Lavis, and Eric Betzig. Imaging Live-Cell Dynamics and Structure at the Single-Molecule Level. *Mol. Cell*, 58(4):644, 2015.

[157] Ulrike Schnell, Freark Dijk, Klaas A. Sjollema, and Ben N.G. Giepmans. Immunolabeling artifacts and the need for live-cell imaging. *Nat. Methods*, 9(2):152–158, 2012.

[158] Yuanqing Chao and Tong Zhang. Optimization of fixation methods for observation of bacterial cell morphology and surface ultrastructures by atomic force microscopy. *Appl. Microbiol. Biotechnol.*, 92(2):381–392, 2011.

[159] Thomas A. Owen-Hughes, Graham D. Pavitt, Diogenes S. Santos, Julie M. Sidebotham, Christopher S J Hulton, Jay C D Hinton, and Christopher F. Higgins. The chromatin-associated protein H-NS interacts with curved DNA to influence DNA topology and gene expression. *Cell*, 71(2):255–265, 1992.

[160] Minsang Shin, Arvin Cesar Lagda, Jae Woong Lee, Abhay Bhat, Joon Haeng Rhee, Jeong Sun Kim, Kunio Takeyasu, and Hyon E. Choy. Gene silencing by H-NS from distal DNA site. *Mol. Microbiol.*, 86(3):707–719, 2012.

[161] Bart J.A.M. Jordi, Anne E. Fielder, Christopher M. Burns, Jay C.D. Hinton, Nir Dover, David W. Ussery, and Christopher F. Higgins. DNA binding is not sufficient for H-NS-mediated repression of proU expression. *J. Biol. Chem.*, 272(18):12083–12090, 1997.

[162] P Bertin, E Terao, E H Lee, P Lejeune, C Colson, a Danchin, and E Collatz. The H-NS protein is involved in the biogenesis of flagella in Escherichia coli. *J. Bacteriol.*, 176(17):5537–40, sep 1994.

[163] M Ko and C Park. Two novel flagellar components and H-NS are involved in the motor function of Escherichia coli. *J. Mol. Biol.*, 303(3):371–82, oct 2000.

[164] Eun A Kim and David F. Blair. Function of the Histone-Like Protein H-NS in Motility of Escherichia coli: Multiple Regulatory Roles Rather than Direct Action at the Flagellar Motor. *J. Bacteriol.*, 197(19):3110–3120, 2015.

[165] Michelle M Barnhart and Matthew R Chapman. NIH Public Access. pages 131–147, 2010.

[166] Douglas Hanahan. Studies on transformation of Escherichia coli with plasmids. *J. Mol. Biol.*, 166(4):557–580, 1983.

[167] F. R. Blattner. The Complete Genome Sequence of Escherichia coli K-12. *Science (80-.).*, 277(5331):1453–1462, 1997.

[168] B Alberts, A Johnson, J Lewis, M Raff, K Roberts, and P Walter. *Molecular Biology of the cell, 6th Ed.* Springer, 2015.

[169] Ariane Briegel and Grant Jensen. Progress and potential of electron cryotomography as illustrated by its application to bacterial chemoreceptor arrays. *Annual review of biophysics*, 46:1–21, 2017.

[170] Joseph J Falke and Kene N Piasta. Architecture and signal transduction mechanism of the bacterial chemosensory array: Progress, controversies, and challenges. *Current opinion in structural biology*, 29:85–94, 2014.

[171] Howard C Berg. *E. coli in Motion.* Springer, 2004.

[172] Jeffrey E Segall, Steven M Block, and Howard C Berg. Temporal comparisons in bacterial chemotaxis. *Proceedings of the National Academy of Sciences*, 83(23):8987–8991, 1986.

[173] Shuangyu Bi and Victor Sourjik. Stimulus sensing and signal processing in bacterial chemotaxis. *Current opinion in microbiology*, 45:22–29, 2018.

[174] Naama Barkai and Stan Leibler. Robustness in simple biochemical networks. *Nature*, 387(6636):913, 1997.

[175] MR Alley, Janine R Maddock, and Lucille Shapiro. Polar localization of a bacterial chemoreceptor. *Genes & development*, 6(5):825–836, 1992.

[176] Janine R Maddock and Lucille Shapiro. Polar location of the chemoreceptor complex in the escherichia coli cell. *Science*, 259(5102):1717–1723, 1993.

[177] Victor Sourjik and Howard C Berg. Localization of components of the chemotaxis machinery of escherichia coli using fluorescent protein fusions. *Molecular microbiology*, 37(4):740–751, 2000.

[178] Sebastian Thiem, David Kentner, and Victor Sourjik. Positioning of chemosensory clusters in e. coli and its relation to cell division. *The EMBO journal*, 26(6):1615–1623, 2007.

[179] Hanbin Mao, Paul S Cremer, and Michael D Manson. A sensitive, versatile microfluidic assay for bacterial chemotaxis. *Proceedings of the National Academy of Sciences*, 100(9):5449–5454, 2003.

[180] Dennis Bray, Matthew D Levin, and Carl J Morton-Firth. Receptor clustering as a cellular mechanism to control sensitivity. *Nature*, 393(6680):85–88, 1998.

[181] TAJ Duke and D Bray. Heightened sensitivity of a lattice of membrane receptors. *Proceedings of the National Academy of Sciences*, 96(18):10104–10108, 1999.

[182] Bernardo A Mello and Yuhai Tu. Quantitative modeling of sensitivity in bacterial chemotaxis: the role of coupling among different chemoreceptor species. *Proceedings of the National Academy of Sciences*, 100(14):8223–8228, 2003.

[183] Victor Sourjik. Receptor clustering and signal processing in E. coli chemotaxis. *Trends Microbiol.*, 12(12):569–76, dec 2004.

[184] Juan E Keymer, Robert G Endres, Monica Skoge, Yigal Meir, and Ned S Wingreen. Chemosensing in escherichia coli: two regimes of two-state receptors. *Proceedings of the National Academy of Sciences*, 103(6):1786–1791, 2006.

[185] Germán E Piñas, Vered Frank, Ady Vaknin, and John S Parkinson. The source of high signal cooperativity in bacterial chemosensory arrays. *Proceedings of the National Academy of Sciences*, 113(12):3335–3340, 2016.

[186] Vered Frank, Germán E Piñas, Harel Cohen, John S Parkinson, and Ady Vaknin. Networked chemoreceptors benefit bacterial chemotaxis performance. *MBio*, 7(6):e01824–16, 2016.

[187] Louisa Liberman, Howard C Berg, and Victor Sourjik. Effect of chemoreceptor modification on assembly and activity of the receptor-kinase complex in escherichia coli. *Journal of bacteriology*, 186(19):6643–6646, 2004.

[188] Motohiro Homma, Daisuke Shiomi, Michio Homma, and Ikuro Kawagishi. Attractant binding alters arrangement of chemoreceptor dimers within its cluster at a cell pole. *Proceedings of the National Academy of Sciences of the United States of America*, 101(10):3462–3467, 2004.

[189] Allison C Lamanna, George W Ordal, and Laura L Kiessling. Large increases in attractant concentration disrupt the polar localization of bacterial chemoreceptors. *Molecular microbiology*, 57(3):774–785, 2005.

[190] M Jack Borrok, Erin M Kolonko, and Laura L Kiessling. Chemical probes of bacterial signal transduction reveal that repellents stabilize and attractants destabilize the chemoreceptor array. *ACS chemical biology*, 3(2):101–109, 2008.

[191] Kang Wu, Hanna E Walukiewicz, George D Glekas, George W Ordal, and Christopher V Rao. Attractant binding induces distinct structural changes to the polar and lateral signaling clusters in bacillus subtilis chemotaxis. *Journal of Biological Chemistry*, 286(4):2587–2595, 2011.

[192] Ariane Briegel, Xiaoxiao Li, Alexandrine M Bilwes, Kelly T Hughes, Grant J Jensen, and Brian R Crane. Bacterial chemoreceptor arrays are hexagonally packed trimers of receptor dimers networked by rings of kinase and coupling proteins. *Proceedings of the National Academy of Sciences*, 109(10):3766–3771, 2012.

[193] J Liu, B Hu, D R Morado, S Jani, M D Manson, and W Margolin. PNAS Plus: Molecular architecture of chemoreceptor arrays revealed by cryoelectron tomography of Escherichia coli minicells. *Proc. Natl. Acad. Sci. U. S. A.*, 109(3):E1481—-E1488, 2012.

[194] Ariane Briegel, Morgan Beeby, Martin Thanbichler, and Grant J Jensen. Activated chemoreceptor arrays remain intact and hexagonally packed. *Molecular microbiology*, 82(3):748–757, 2011.

[195] Cezar M Khursigara, Ganhui Lan, Silke Neumann, Xiongwu Wu, Suchie Ravindran, Mario J Borgnia, Victor Sourjik, Jacqueline Milne, Yuhai Tu, and Sriram Subramaniam. Lateral density of receptor arrays in the membrane plane influences sensitivity of the e. coli chemotaxis response. *The EMBO journal*, 30(9):1719–1729, 2011.

[196] Vered Frank and Ady Vaknin. Prolonged stimuli alter the bacterial chemosensory clusters. *Molecular microbiology*, 88(3):634–644, 2013.

[197] Eric Betzig, George H Patterson, Rachid Sougrat, O Wolf Lindwasser, Scott Olenych, Juan S Bonifacino, Michael W Davidson, Jennifer Lippincott-Schwartz, and Harald F Hess. Imaging intracellular fluorescent proteins at nanometer resolution. *Science*, 313(5793):1642–1645, 2006.

[198] Derek Greenfield, Ann L McEvoy, Hari Shroff, Gavin E Crooks, Ned S Wingreen, Eric Betzig, and Jan Liphardt. Self-organization of the escherichia coli chemotaxis network imaged with super-resolution light microscopy. *PLoS biology*, 7(6):e1000137, 2009.

[199] Sang-Hyuk Lee, Jae Yen Shin, Antony Lee, and Carlos Bustamante. Counting single photoactivatable fluorescent molecules by photoactivated localization microscopy (palm). *Proceedings of the National Academy of Sciences*, 109(43):17436–17441, 2012.

[200] J Solari, F Anquez, KM Scherer, and TS Shimizu. Bacterial chemoreceptor imaging at high spatiotemporal resolution using photoconvertible fluorescent proteins. *Meth Mol Biol*, 1729:203–231, 2018.

[201] Sean A McKinney, Christopher S Murphy, Kristin L Hazelwood, Michael W Davidson, and Loren L Looger. A bright and photostable photoconvertible fluorescent protein for fusion tags. *Nature methods*, 6(2):131, 2009.

[202] JOHN S Parkinson and SUSAN E Houts. Isolation and behavior of escherichia coli deletion mutants lacking chemotaxis functions. *Journal of bacteriology*, 151(1):106–113, 1982.

[203] Thomas S Shimizu, Sergej V Aksenov, and Dennis Bray. A spatially extended stochastic model of the bacterial chemotaxis signalling pathway. *Journal of molecular biology*, 329(2):291–309, 2003.

[204] Bernardo A Mello and Yuhai Tu. An allosteric model for heterogeneous receptor complexes: understanding bacterial chemotaxis responses to multiple stimuli. *Proceedings of the National Academy of Sciences of the United States of America*, 102(48):17354–17359, 2005.

[205] Robert M Macnab and DE Koshland. The gradient-sensing mechanism in bacterial chemotaxis. *Proceedings of the National Academy of Sciences*, 69(9):2509–2512, 1972.

[206] J. Adler. Chemotaxis in Bacteria. *Science (80-.).*, 153(3737):708–716, aug 1966.

[207] Steven M Block, Jeffery E Segall, and Howard C Berg. Adaptation kinetics in bacterial chemotaxis. *Journal of bacteriology*, 154(1):312–323, 1983.

[208] Yue Li, Luay M Almassalha, John E Chandler, Xiang Zhou, Yolanda E Stypula-Cyrus, Karl A Hujsak, Eric W Roth, Reiner Bleher, Hariharan Subramanian, Igal Szleifer, et al. The effects of chemical fixation on the cellular nanostructure. *Experimental cell research*, 358(2):253–259, 2017.

[209] Dongmyung Oh, Yang Yu, Hochan Lee, Barry L. Wanner, and Ken Ritchie. Dynamics of the serine chemoreceptor in the escherichia coli inner membrane: A high-speed single-molecule tracking study. *Biophys. J.*, 106(1):145–153, 2014.

[210] P. G. Saffman and M Delbruck. Brownian motion in biological membranes. *Proc Natl Acad Sci USA*, 72(8):3111–3113, 1975.

[211] Felix Oswald, Aravindan Varadarajan, Holger Lill, Erwin J.G. Peterman, and Yves J.M. Bollen. MreB-Dependent Organization of the E. coli Cytoplasmic Membrane Controls Membrane Protein Diffusion. *Biophys. J.*, 110(5):1139–1149, 2016.

[212] Ryota Iino, Ikuko Koyama, and Akihiro Kusumi. Single molecule imaging of green fluorescent proteins in living cells: E-cadherin forms oligomers on the free cell surface. *Biophysical journal*, 80(6):2667–2677, 2001.

[213] Mohit Kumar, Mario S Mommer, and Victor Sourjik. Mobility of cytoplasmic, membrane, and DNA-binding proteins in Escherichia coli. *Biophys. J.*, 98(4):552–9, mar 2010.

[214] J Schuster, F Cichos, and C Von Borczyskowski. Diffusion measurements by single-molecule spot-size analysis. *The Journal of Physical Chemistry A*, 106(22):5403–5406, 2002.

[215] Johan Elf, Gene-Wei Li, and X Sunney Xie. Probing transcription factor dynamics at the single-molecule level in a living cell. *Science*, 316(5828):1191–4, may 2007.

[216] Hannah H Tuson and Julie S Biteen. Unveiling the inner workings of live bacteria using super-resolution microscopy. *Analytical chemistry*, 87(1):42–63, 2014.

[217] Ji Yu, Jie Xiao, Xiaojia Ren, Kaiqin Lao, and X Sunney Xie. Probing gene expression in live cells, one protein molecule at a time. *Science*, 311(5767):1600–1603, 2006.

[218] Christian L. Vestergaard, Paul C. Blainey, and Henrik Flyvbjerg. Optimal estimation of diffusion coefficients from single-particle trajectories. *Phys. Rev. E*, 89(2):022726, feb 2014.

[219] Daniel Thédié, Romain Berardozzi, Virgile Adam, and Dominique Bourgeois. Photoswitching of Green mEos2 by Intense 561 nm Light Perturbs Efficient Green-to-Red Photoconversion in Localization Microscopy. *J. Phys. Chem. Lett.*, 8(18):4424–4430, 2017.

[220] Germán E. Piñas, Vered Frank, Ady Vaknin, and John S. Parkinson. The source of high signal cooperativity in bacterial chemosensory arrays. *Proc. Natl. Acad. Sci.*, 113(12):201600216, 2016.

[221] Christian L Vestergaard. Optimizing experimental parameters for tracking of diffusing particles. *Physical Review E*, 94(2):022401, 2016.

[222] Jason E Gestwicki, Allison C Lamanna, Rasika M Harshey, Linda L McCarter, Laura L Kiessling, and Julius Adler. Evolutionary conservation of methyl-accepting chemotaxis protein location in bacteria andarchaea. *Journal of Bacteriology*, 182(22):6499–6502, 2000.

[223] George H Wadhams and Judith P Armitage. Making sense of it all: bacterial chemotaxis. *Nature Reviews Molecular Cell Biology*, 5(12):1024–1037, 2004.

[224] Ariane Briegel, Davi R Ortega, Elitza I Tocheva, Kristin Wuichet, Zhuo Li, Songye Chen, Axel Müller, Cristina V Iancu, Gavin E Murphy, Megan J Dobro, et al. Universal architecture of bacterial chemoreceptor arrays. *Proceedings of the National Academy of Sciences*, pages pnas–0905181106, 2009.

[225] T Duke and D Bray. Heightened sensitivity of a lattice of membrane receptors. *Proc. Natl. Acad. Sci. U. S. A.*, 96(18):10104–8, 1999.

[226] Victor Sourjik and Howard C Berg. Binding of the Escherichia coli response regulator CheY to its target measured in vivo by fluorescence resonance energy transfer. *Proc. Natl. Acad. Sci. U. S. A.*, 99(20):12669–12674, 2002.

[227] Mingshan Li and Gerald L Hazelbauer. Adaptational assistance in clusters of bacterial chemoreceptors. *Molecular microbiology*, 56(6):1617–1626, 2005.

[228] Robert G Endres and Ned S Wingreen. Precise adaptation in bacterial chemotaxis through "assistance neighborhoods". *Proceedings of the National Academy of Sciences*, 103(35):13040–13044, 2006.

[229] Yuhai Tu, Thomas S Shimizu, and Howard C Berg. Modeling the chemotactic response of escherichia coli to time-varying stimuli. *Proceedings of the National Academy of Sciences*, 105(39):14855–14860, 2008.

[230] Thomas S Shimizu, Yuhai Tu, and Howard C Berg. A modular gradient-sensing network for chemotaxis in escherichia coli revealed by responses to time-varying stimuli. *Molecular systems biology*, 6(1), 2010.

[231] Milena D Lazova, Tanvir Ahmed, Domenico Bellomo, Roman Stocker, and Thomas S Shimizu. Response rescaling in bacterial chemotaxis. *Proceedings of the National Academy of Sciences*, 108(33):13870–13875, 2011.

[232] Robert Mesibov, George W Ordal, and Julius Adler. The range of attractant concentrations for bacterial chemotaxis and the threshold and size of response over this range: Weber law and related phenomena. *The Journal of general physiology*, 62(2):203–223, 1973.

[233] Oren Shoval, Lea Goentoro, Yuval Hart, Avi Mayo, Eduardo Sontag, and Uri Alon. Fold-change detection and scalar symmetry of sensory input fields. *Proceedings of the National Academy of Sciences*, page 201002352, 2010.

[234] Bernardo A Mello and Yuhai Tu. Effects of adaptation in maintaining high sensitivity over a wide range of backgrounds for escherichia coli chemotaxis. *Biophysical journal*, 92(7):2329–2337, 2007.

[235] Yevgeniy V Kalinin, Lili Jiang, Yuhai Tu, and Mingming Wu. Logarithmic sensing in escherichia coli bacterial chemotaxis. *Biophysical journal*, 96(6):2439–2448, 2009.

[236] Vered Frank and Ady Vaknin. Prolonged stimuli alter the bacterial chemosensory clusters. *Mol. Microbiol.*, 88(3):634–644, 2013.

[237] Jeffrey E Segall, Michael D Manson, and Howard C Berg. Signal processing times in bacterial chemotaxis. *Nature*, 296(5860):855, 1982.

[238] Victor Sourjik and Howard C Berg. Binding of the escherichia coli response regulator chey to its target measured in vivo by fluorescence resonance energy transfer. *Proceedings of the National Academy of Sciences*, 99(20):12669–12674, 2002.

[239] Johannes M Keegstra, Keita Kamino, François Anquez, Milena D Lazova, Thierry Emonet, and Thomas S Shimizu. Phenotypic diversity and temporal variability in a bacterial signaling network revealed by single-cell fret. *ELife*, 6:e27455, 2017.

[240] Remy Colin, Christelle Rosazza, Ady Vaknin, and Victor Sourjik. Multiple sources of slow activity fluctuations in a bacterial chemosensory network. *ELife*, 6:e26796, 2017.

[241] Annette H Erbse and Joseph J Falke. The core signaling proteins of bacterial chemotaxis assemble to form an ultrastable complex. *Biochemistry*, 48(29):6975–6987, 2009.

[242] Ekaterina Korobkova, Thierry Emonet, Jose MG Vilar, Thomas S Shimizu, and Philippe Cluzel. From molecular noise to behavioural variability in a single bacterium. *Nature*, 428(6982):574, 2004.

[243] Franziska Matthäus, Marko Jagodič, and Jure Dobnikar. E. coli superdiffusion and chemotaxis—search strategy, precision, and motility. *Biophysical journal*, 97(4):946–957, 2009.

[244] Marlo Flores, Thomas S Shimizu, Pieter Rein ten Wolde, and Filipe Tostevin. Signaling noise enhances chemotactic drift of e. coli. *Physical review letters*, 109(14):148101, 2012.

[245] Mingshan Li and Gerald L Hazelbauer. Cellular stoichiometry of the components of the chemotaxis signaling complex. *Journal of bacteriology*, 186(12):3687–3694, 2004.

[246] Hanna Salman and Albert Libchaber. A concentration-dependent switch in the bacterial response to temperature. *Nature cell biology*, 9(9):1098, 2007.

[247] Yevgeniy Kalinin, Silke Neumann, Victor Sourjik, and Mingming Wu. Responses of escherichia coli bacteria to two opposing chemoattractant gradients depend on the chemoreceptor ratio. *Journal of bacteriology*, 192(7):1796–1800, 2010.

[248] Moriah Koler, Eliran Peretz, Chetan Aditya, Thomas S. Shimizu, 2, and Ady Vaknin. Long-term positioning and polar preference of chemoreceptor clusters in *E. coli*. *Nature Communications*, *in press*, 2018.

[249] Victor Sourjik and Howard C Berg. Receptor sensitivity in bacterial chemotaxis. *Proceedings of the National Academy of Sciences*, 99(1):123–127, 2002.

[250] Victor Sourjik, Ady Vaknin, Thomas S Shimizu, and Howard C Berg. [17]-in vivo measurement by fret of pathway activity in bacterial chemotaxis. *Methods in enzymology*, 423:365–391, 2007.

[251] Makio Tokunaga, Naoko Imamoto, and Kumiko Sakata-Sogawa. Highly inclined thin illumination enables clear single-molecule imaging in cells. *Nature methods*, 5(2):159–161, 2008.

[252] Michael J Rust, Mark Bates, and Xiaowei Zhuang. Sub-diffraction-limit imaging by stochastic optical reconstruction microscopy (storm). *Nature methods*, 3(10):793–796, 2006.

[253] Max Born and Emil Wolf. *Principles of optics: electromagnetic theory of propagation, interference and diffraction of light*. CUP Archive, 2000.

[254] Travis J Gould, Vladislav V Verkhusha, and Samuel T Hess. Imaging biological structures with fluorescence photoactivation localization microscopy. *Nature protocols*, 4(3):291–308, 2009.

[255] Jean-Christophe Olivo-Marin. Extraction of spots in biological images using multiscale products. *Pattern recognition*, 35(9):1989–1996, 2002.

[256] Russell E Thompson, Daniel R Larson, and Watt W Webb. Precise nanometer localization analysis for individual fluorescent probes. *Biophysical journal*, 82(5):2775–2783, 2002.

[257] Bo Zhang, Josiane Zerubia, and Jean-Christophe Olivo-Marin. Gaussian approximations of fluorescence microscope point-spread function models. *Applied Optics*, 46(10):1819–1829, 2007.

[258] Kim I Mortensen, L Stirling Churchman, James A Spudich, and Henrik Flyvbjerg. Optimized localization analysis for single-molecule tracking and super-resolution microscopy. *nature methods*, 7(5):377–381, 2010.

[259] Paolo Annibale, Stefano Vanni, Marco Scarselli, Ursula Rothlisberger, and Aleksandra Radenovic. Quantitative photo activated localization microscopy: unraveling the effects of photoblinking. *PloS one*, 6(7):e22678, 2011.

[260] P Annibale, M Scarselli, A Kodiyan, and A Radenovic. Photoactivatable fluorescent protein meos2 displays repeated photoactivation after a long-lived dark state in the red

photoconverted form. *The Journal of Physical Chemistry Letters*, 1(9):1506–1510, 2010.

[261] Xavier Michalet. Mean square displacement analysis of single-particle trajectories with localization error: Brownian motion in an isotropic medium. *Phys. Rev. E - Stat. Nonlinear, Soft Matter Phys.*, 82(4):1–13, 2010.

[262] Andrew J. Berglund. Statistics of camera-based single-particle tracking. *Phys. Rev. E*, 82(1):011917, 2010.

[263] Elias M Puchner, Jessica M Walter, Robert Kasper, Bo Huang, and Wendell A Lim. Counting molecules in single organelles with superresolution microscopy allows tracking of the endosome maturation trajectory. *Proceedings of the National Academy of Sciences*, 110(40):16015–16020, 2013.

[264] R. M. Zucker. Quality Assessment of Confocal Microscopy Slide Based Systems: Performance. *J. Int. Soc. Anal. Cytol.*, 69(A):659–676, 2006.

[265] Silke Neumann, Linda Løvdok, Kajetan Bentele, Johannes Meisig, Ekkehard Ullner, Ferencz S. Paldy, Victor Sourjik, and Markus Kollmann. Exponential signaling gain at the receptor level enhances signal-to-noise ratio in bacterial chemotaxis. *PLoS One*, 9(4):1–11, 2014.

[266] Ady Vaknin and Howard C Berg. Osmotic stress mechanically perturbs chemoreceptors in escherichia coli. *Proceedings of the National Academy of Sciences*, 103(3):592–596, 2006.

[267] Dirk Landgraf, Burak Okumus, Peter Chien, Tania A Baker, and Johan Paulsson. Segregation of molecules at cell division reveals native protein localization. *Nature methods*, 9(5):480, 2012.

[268] Mingshu Zhang, Hao Chang, Yongdeng Zhang, Junwei Yu, Lijie Wu, Wei Ji, Juanjuan Chen, Bei Liu, Jingze Lu, Yingfang Liu, et al. Rational design of true monomeric and bright photoactivatable fluorescent proteins. *Nature methods*, 9(7):727–729, 2012.

[269] S. Wang, J. R. Moffitt, G. T. Dempsey, X. S. Xie, and X. Zhuang. Characterization and development of photoactivatable fluorescent proteins for single-molecule-based superresolution imaging. *Proc. Natl. Acad. Sci.*, 111(23), may 2014.

[270] Tamas Gaal, Benjamin P. Bratton, Patricia Sanchez-Vazquez, Alexander Sliwicki, Kristine Sliwicki, Andrew Vegel, Rachel Pannu, and Richard L. Gourse. Colocalization

of distant chromosomal loci in space in E. coli: a bacterial nucleolus. *Genes Dev.*, 30(20):2272–2285, 2016.

[271] Martial Marbouty, Antoine Le Gall, Diego I. Cattoni, Axel Cournac, Alan Koh, Jean-Bernard Fiche, Julien Mozziconacci, Heath Murray, Romain Koszul, and Marcelo Nollmann. Condensin- and Replication-Mediated Bacterial Chromosome Folding and Origin Condensation Revealed by Hi-C and Super-resolution Imaging. *Mol. Cell*, 59(4):588–602, 2015.

[272] Tung B K Le, Maxim V Imakaev, Leonid a Mirny, and Michael T Laub. High-Resolution Mapping of the Spatial Organization of a Bacterial Chromosome. *Science*, 731, oct 2013.

[273] Virginia S. Lioy, Axel Cournac, Martial Marbouty, Stéphane Duigou, Julien Mozziconacci, Olivier Espéli, Frédéric Boccard, and Romain Koszul. Multiscale Structuring of the E. coli Chromosome by Nucleoid-Associated and Condensin Proteins. *Cell*, pages 1–13, 2018.

[274] JM Van Helvoort, J Kool, and CL Woldringh. Chloramphenicol causes fusion of separated nucleoids in escherichia coli k-12 cells and filaments. *Journal of bacteriology*, 178(14):4289–4293, 1996.

[275] Julio E. Cabrera and Ding J. Jin. Active transcription of rRNA operons is a driving force for the distribution of RNA polymerase in bacteria: Effect of extrachromosomal copies of rrnB on the in vivo localization of RNA polymerase. *J. Bacteriol.*, 188(11):4007–4014, 2006.

[276] Martin Thanbichler and Lucy Shapiro. Chromosome organization and segregation in bacteria. *J. Struct. Biol.*, 156(2):292–303, nov 2006.

[277] Xindan Wang, Paula Montero Llopis, and David Z Rudner. Organization and segregation of bacterial chromosomes. *Nat. Rev. Genet.*, 14(3):191–203, feb 2013.

[278] Elizabeth a Libby, Manuela Roggiani, and Mark Goulian. Membrane protein expression triggers chromosomal locus repositioning in bacteria. *Proc. Natl. Acad. Sci. U. S. A.*, 109(19):7445–50, may 2012.

[279] Nick Gilbert and James Allan. Supercoiling in DNA and chromatin. *Curr. Opin. Genet. Dev.*, 25(1):15–21, 2014.

[280] Mahdi Golkaram, Stefan Hellander, Brian Drawert, and Linda R. Petzold. Macromolecular Crowding Regulates the Gene Expression Profile by Limiting Diffusion. *PLoS Comput. Biol.*, 12(11):1–16, 2016.

[281] Cheemeng Tan, Saumya Saurabh, Marcel P. Bruchez, Russell Schwartz, and Philip Leduc. Molecular crowding shapes gene expression in synthetic cellular nanosystems. *Nat. Nanotechnol.*, 8(8):602–608, 2013.

[282] Robert S Fuller, Jon M Kaguni, and Arthur Kornberg. Enzymatic replication of the origin of the Escherichia coli chromosome (oriC plasmids/dnaA gene/DNA replication). *Biochemistry*, 78(12):7370–7374, 1981.

[283] E. Sokolova, E. Spruijt, M. M. K. Hansen, E. Dubuc, J. Groen, V. Chokkalingam, A. Piruska, H. A. Heus, and W. T. S. Huck. Enhanced transcription rates in membrane-free protocells formed by coacervation of cell lysate. *Proc. Natl. Acad. Sci.*, 110(29):11692–11697, 2013.

[284] Tyler N. Shendruk, Martin Bertrand, Hendrick W. De Haan, James L. Harden, and Gary W. Slater. Simulating the entropic collapse of coarse-grained chromosomes. *Biophys. J.*, 108(4):810–820, 2015.

[285] Chanil Jeon, Youngkyun Jung, and Bae Yeun Ha. A ring-polymer model shows how macromolecular crowding controls chromosome-arm organization in Escherichia coli. *Sci. Rep.*, 7(1):1–10, 2017.

[286] M. Schaechter, O. MaalOe, and N. O. Kjeldgaard. Dependency on Medium and Temperature of Cell Size and Chemical Composition during Balanced Growth of Salmonella typhimurium. *J. Gen. Microbiol.*, 19(3):592–606, 1958.

[287] M. Scott, S. Klumpp, E. M. Mateescu, and T. Hwa. Emergence of robust growth laws from optimal regulation of ribosome synthesis. *Mol. Syst. Biol.*, 10(8):747–747, 2014.

[288] Teuta Pilizota and Joshua W. Shaevitz. Plasmolysis and cell shape depend on solute outer-membrane permeability during hyperosmotic shock in E. coli. *Biophys. J.*, 104(12):2733–2742, 2013.

[289] Renata Buda, Yunxiao Liu, Jin Yang, Smitha Hegde, Keiran Stevenson, Fan Bai, and Teuta Pilizota. Dynamics of <i>Escherichia coli</i> ’s passive response to a sudden decrease in external osmolarity. *Proc. Natl. Acad. Sci.*, 113(40):E5838–E5846, 2016.

[290] Suckjoon Jun and Bela Mulder. Entropy-driven spatial organization of highly confined polymers: lessons for the bacterial chromosome. *Proc. Natl. Acad. Sci. U. S. A.*, 103(33):12388–93, 2006.

[291] Debasish Chaudhuri and Bela M. Mulder. Spontaneous helicity of a polymer with side loops confined to a cylinder. *Phys. Rev. Lett.*, 108(26):1–5, 2012.

[292] Renko De Vries. DNA condensation in bacteria: Interplay between macromolecular crowding and nucleoid proteins. *Biochimie*, 92(12):1715–1721, 2010.

[293] Conrad L Woldringh, Peter Ruhdal Jensen, and Hans V Westerhoff. Structure and partitioning of bacterial dna: determined by a balance of compaction and expansion forces? *FEMS microbiology letters*, 131(3):235–242, 1995.

[294] R. T. Dame. H-NS mediated compaction of DNA visualised by atomic force microscopy. *Nucleic Acids Res.*, 28(18):3504–3510, 2000.

[295] Anna S. Wegner, Kathelijne Wintraecken, Roberto Spurio, Conrad L. Woldringh, Renko de Vries, and Theo Odijk. Compaction of isolated Escherichia coli nucleoids: Polymer and H-NS protein synergetics. *J. Struct. Biol.*, 194(1):129–137, 2016.

[296] Chanil Jeon, Juin Kim, Hawoong Jeong, Youngkyun Jung, and Bae-Yeun Ha. Chromosome-like organization of an asymmetrical ring polymer confined in a cylindrical space. *Soft Matter*, 11(41):8179–8193, 2015.

[297] Ryan P. Joyner, Jeffrey H. Tang, Jonne Helenius, Elisa Dultz, Christiane Brune, Liam J. Holt, Sebastien Huet, Daniel J. Müller, and Karsten Weis. A glucose-starvation response regulates the diffusion of macromolecules. *Elife*, 5(MARCH2016):1–26, 2016.

[298] Peter R Cook. Predicting three-dimensional genome structure from transcriptional activity. *Nature genetics*, 32(3):347, 2002.

[299] Ulrike Dinnbier, Eva Limpinsel, Roland Schmid, and Evert P Bakker. Transient accumulation of potassium glutamate and its replacement by trehalose during adaptation of growing cells of escherichia coli k-12 to elevated sodium chloride concentrations. *Archives of Microbiology*, 150(4):348–357, 1988.

[300] Bettina Kempf and Erhard Bremer. Uptake and synthesis of compatible solutes as microbial stress responses to high-osmolality environments. *Archives of microbiology*, 170(5):319–330, 1998.

[301] Teuta Pilizota and Joshua W Shaevitz. Fast, multiphase volume adaptation to hyperosmotic shock by escherichia coli. *PLoS One*, 7(4):e35205, 2012.

[302] HE Kubitschek. Constancy of the ratio of dna to cell volume in steady-state cultures of escherichia coli br. *Biophysical journal*, 14(2):119, 1974.

[303] D Scott Cayley, Harry J Guttman, and M Thomas Record Jr. Biophysical characterization of changes in amounts and activity of escherichia coli cell and compartment water and turgor pressure in response to osmotic stress. *Biophysical Journal*, 78(4):1748–1764, 2000.

[304] Teuta Pilizota and Joshua W. Shaevitz. Origins of escherichia coli growth rate and cell shape changes at high external osmolality. *Biophys. J.*, 107(8):1962–1969, 2014.

[305] Cedric Cagliero and Ding Jun Jin. Dissociation and re-association of RNA polymerase with DNA during osmotic stress response in Escherichia coli. *Nucleic Acids Res.*, 41(1):315–326, 2013.

[306] Vittore F Scolari and Marco Cosentino Lagomarsino. Combined collapse by bridging and self-adhesion in a prototypical polymer model inspired by the bacterial nucleoid. *Soft Matter*, 11(9):1677–87, 2015.

[307] D. Joseph Clark and O. Maaløe. DNA replication and the division cycle in Escherichia coli. *J. Mol. Biol.*, 23(1):99–112, 1967.

[308] Luc Vincent, Luc Vincent, and Pierre Soille. Watersheds in Digital Spaces: An Efficient Algorithm Based on Immersion Simulations. *IEEE Trans. Pattern Anal. Mach. Intell.*, 13(6):583–598, 1991.

[309] Hu Cang, Anna Labno, Changgui Lu, Xiaobo Yin, Ming Liu, Christopher Gladden, Yongmin Liu, and Xiang Zhang. Probing the electromagnetic field of a 15-nanometre hotspot by single molecule imaging. *Nature*, 469(7330):385–388, 2011.

[310] Michael J Rust, Mark Bates, and Xiaowei Zhuang. Sub-diffraction-limit imaging by stochastic optical reconstruction microscopy (STORM). *Nat. Methods*, 3(10):793–795, 2006.